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Title: HE FRACTURE TESTS - DETERMINATION OF THE
STRESS-BRIDGING LAW

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HE Fracture Tests – Determination of the Stress-Bridging Law¹

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Abstract

Previous experimental observations showed that the fracture process in the sugar mock, a simulant of the PBX 9501 high explosive, is completely different from that in brittle solids, even though the high explosive material PBX 9501 is quite brittle under tension. A close examination of the fracture surface revealed that before crack initiation and propagation, a very large damage region is developed ahead of the crack tip. Since such a damage region is very narrow, it can be modeled as a stress bridging zone. Due to the presence of the sizable bridging zone, conventional fracture mechanics is no longer applicable. Stress bridging has to be considered explicitly in order to understand of fracture processes in the PBX 9501 high explosive and the sugar mock. The key element of the bridging model is the so-called stress-bridging law, which can only be determined through experimental measurement. In this study, fracture experiments on PBX 9501 high explosive using an optical technique were conducted. From the experimental measurement, we determined quantitatively the stress-bridging law, which characterizes the relationship between the bridging stress and the opening displacement cross the bridging zone. In this talk, detailed experimental observations and results will be presented, and future plans regarding the investigation of the fracture behavior of PBX 9501 high explosive will be discussed.

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**HE Fracture Tests – Determination of the
Stress-Bridging Law**

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DX-2: E.L. Roemer, W.J. Wright, D.G. Thompson

Outline

• **Background:**

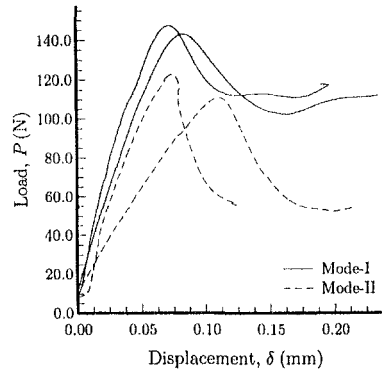
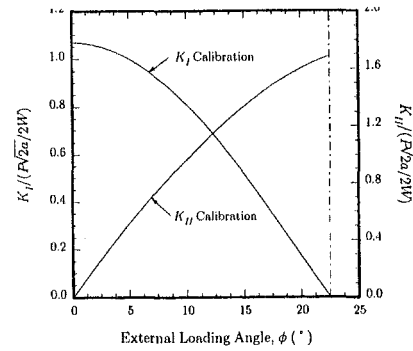
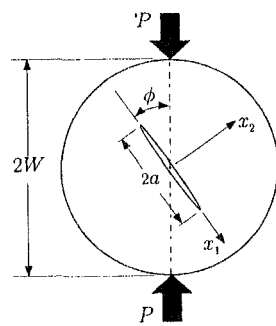
- Previous (failed?) attempt of measuring fracture resistance of PBX 9501 and sugar mock;
- Discovery of the fracture sequence in HE: formation and enlargement of sizable bridging zones.

• **Recent Progresses:**

- Principles of the experimental technique;
- Experimental measurement of the stress-bridging law for PBX 9501.

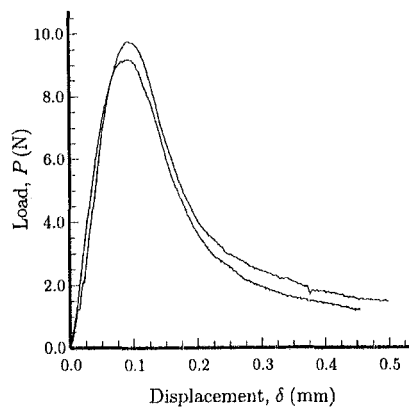
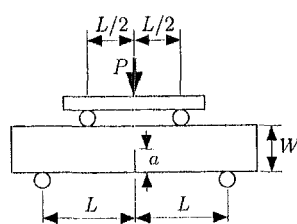
• **Future Plans:**

Brazilian Disk Experiment of Sugar Mock

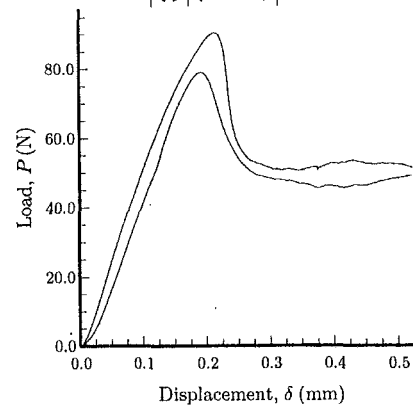
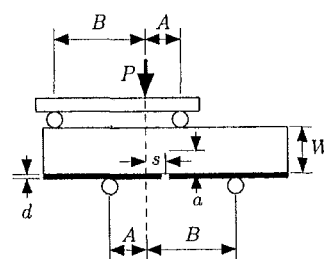


Four-Point Bend Fracture Test of Sugar Mock

Symmetric

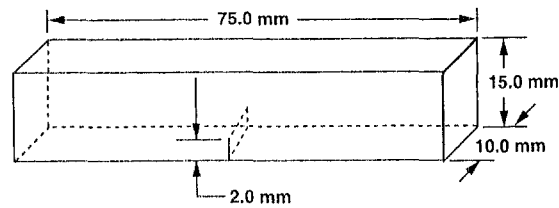


Asymmetric



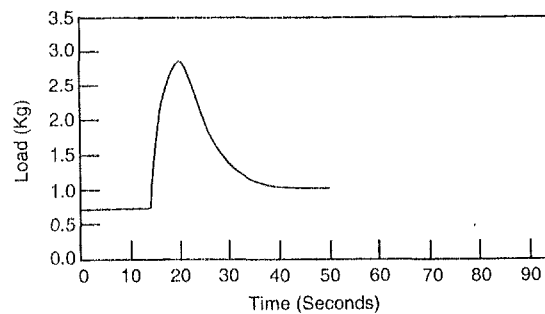
Three-Point Bend Fracture Test of PBX 9501

- PBX 9501 three-point bend specimen:

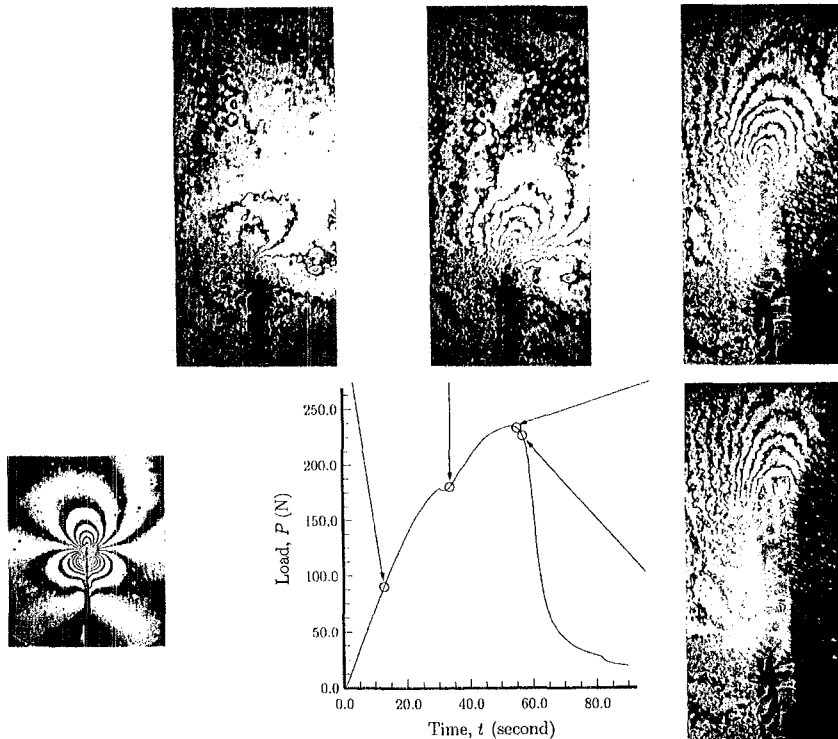


- PBX 9501 three-point bend test record:

3 Point Bend Test, PBX 9501, R.T. #1

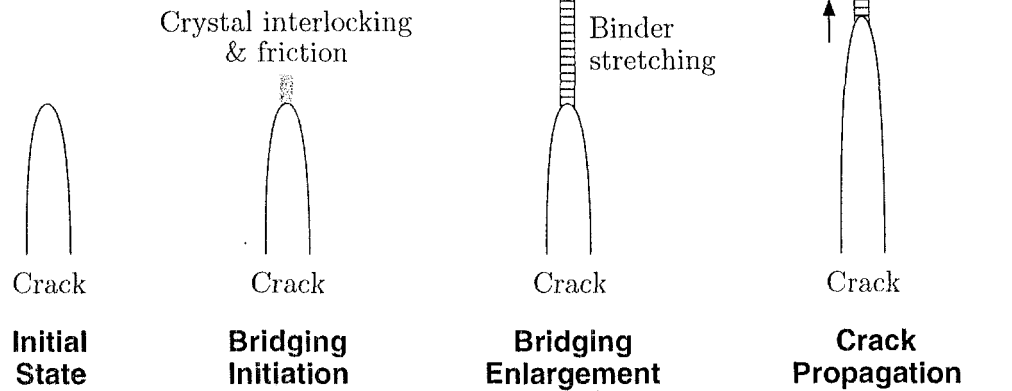


Experimental CGS Fringe Patterns



Fracture Sequence in Sugar Mock (PBX 9501)

Binder Stretching

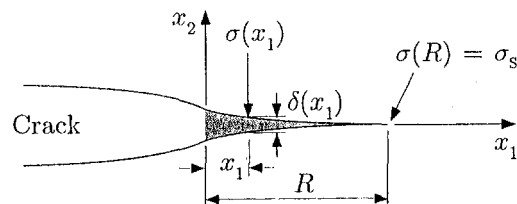


Stress Bridging Model

- Introduce model that explicitly incorporates stress bridging mechanism.

- Ingredients of the model:

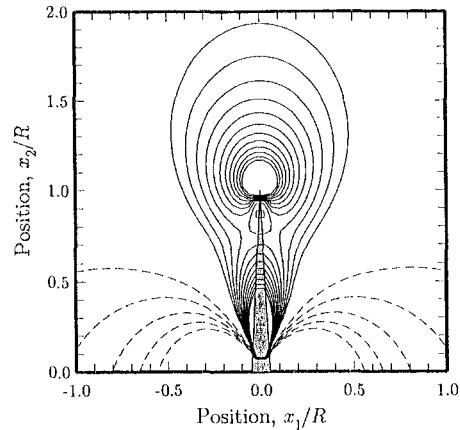
- Bridging zone length: R ;
- Bridging stress: $\sigma(x_1)$;
- Bridging zone opening: $\delta(x_1)$;
- Initiation stress: σ_s .



- Key element of the model: stress-bridging law

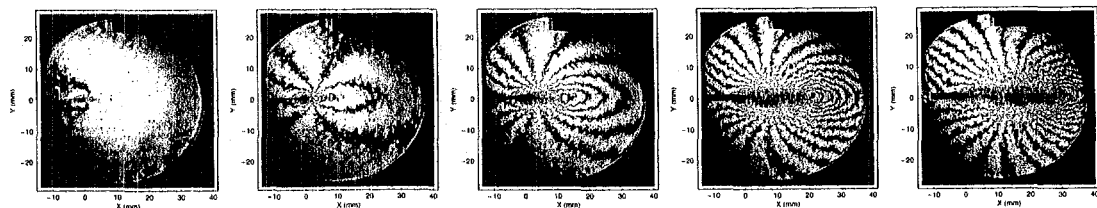
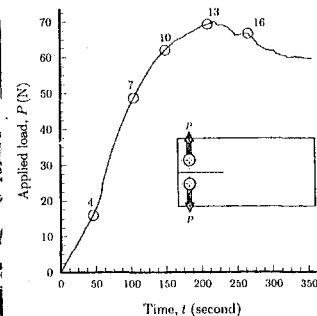
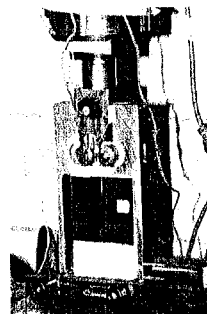
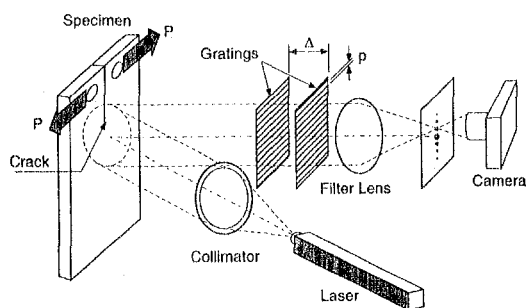
$$\sigma = F(\delta).$$

Comparison with Experimental CGS Pattern



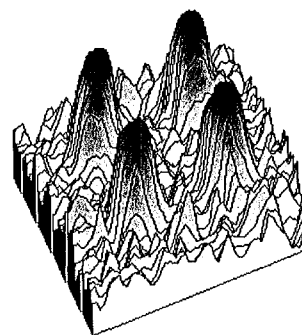
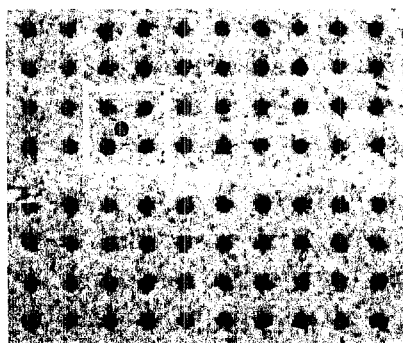
- Failure of the sugar mock (PBX 9501) cannot be characterized by one critical number (K_{IC} , for example) as is the conventional approach in fracture mechanics.
- Stress-bridging law has to be measured through experiments.

Stress-Bridging Law Measurement Using CGS

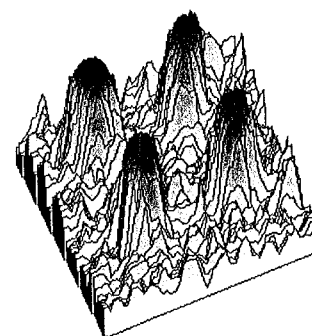
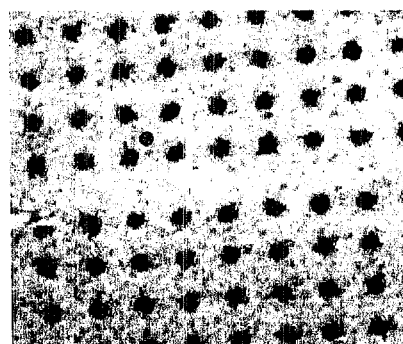


Principle of Digital Image Correlation (DIC)

Before
Deformation



After
Deformation



Mathematical Foundation of Digital Image Correlation

- **Light Intensity:**
$$\begin{cases} I(x) \text{ where } x \in \mathbb{R}, & \text{Before deformation;} \\ I_*(y) \text{ where } y \in \mathbb{R}_*, & \text{After deformation.} \end{cases}$$
- **Mathematical Problem:** For a given pair of $I(x)$ and $I_*(y)$, find a mapping relation $y = \hat{y}(x)$ such that

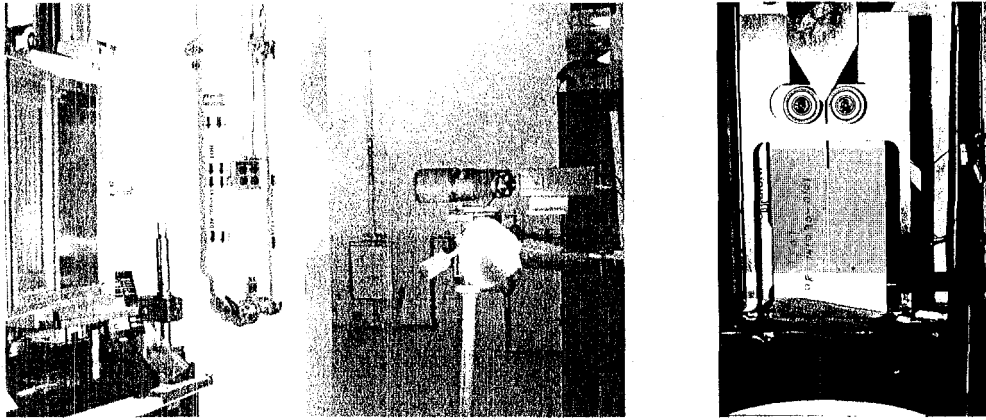
$$I_*(\hat{y}(x)) - I(x) = 0, \quad \forall x \in \mathbb{R}.$$

- **Homogeneous Deformation:** $\hat{y}(x) = Fx + b.$
- **Correlation Coefficient:**

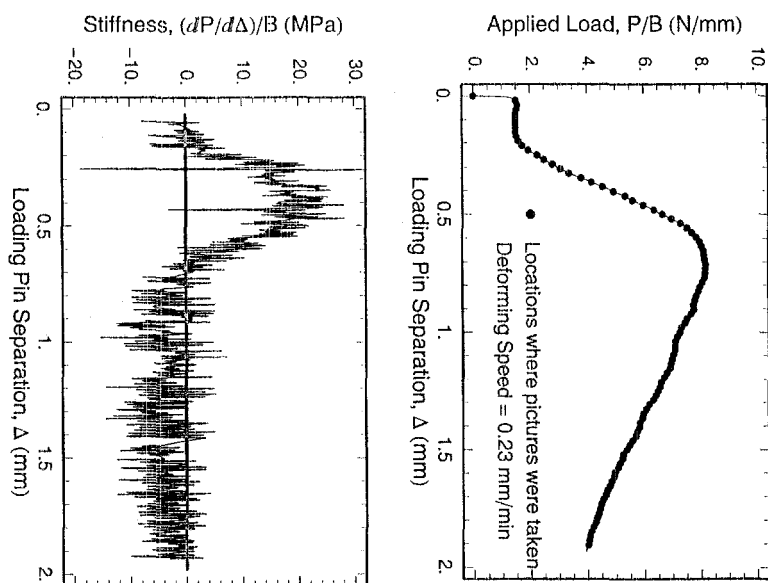
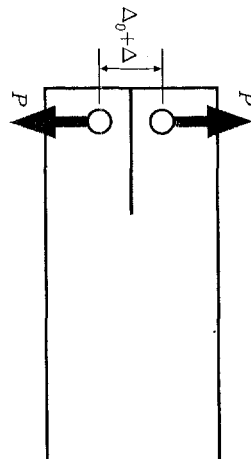
$$C(F, b) = 1 - \frac{\sum_{x \in \mathbb{R}} \{I(x)I_*(Fx + b)\}}{\left\{ \left[\sum_{x \in \mathbb{R}} I^2(x) \right] \left[\sum_{x \in \mathbb{R}} I_*^2(Fx + b) \right] \right\}^{1/2}}, \quad \text{or} \quad \frac{\sum_{x \in \mathbb{R}} \{I_*(Fx + b) - I(x)\}^2}{\sum_{x \in \mathbb{R}} I^2(x)},$$

where $C(F, b) = 0$ corresponds to perfect correlation. Numerically, one needs to find F and b to minimize $C(F, b)$.

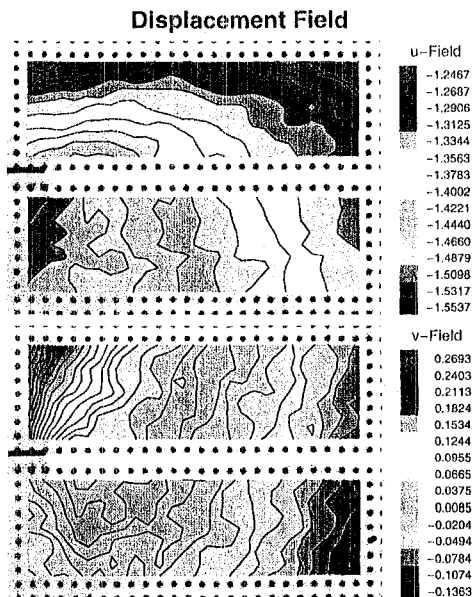
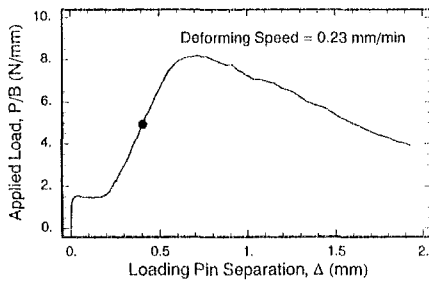
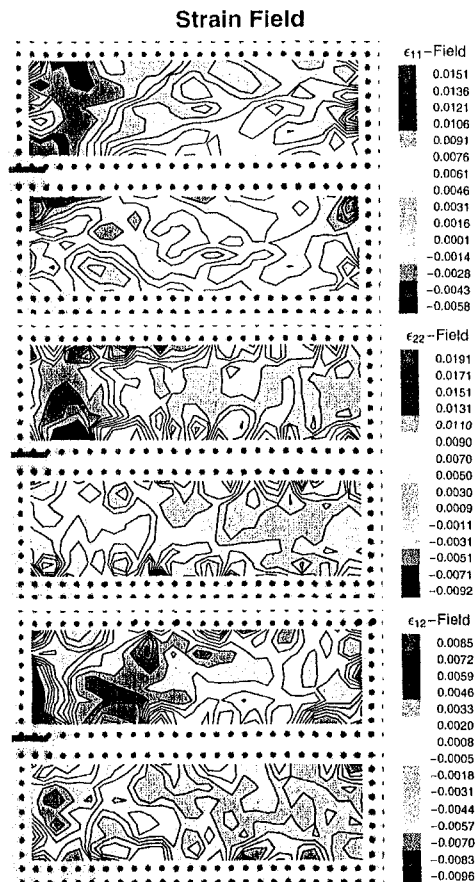
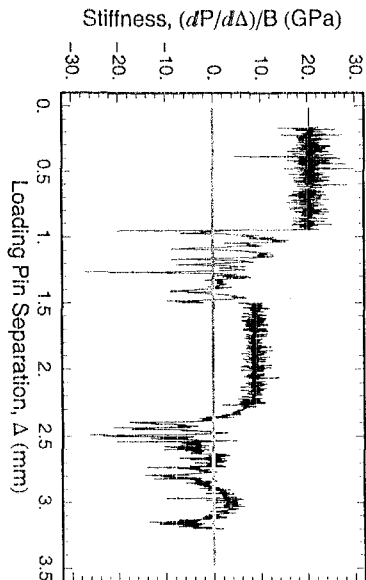
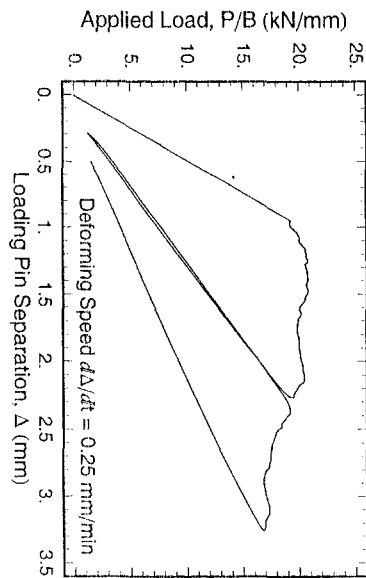
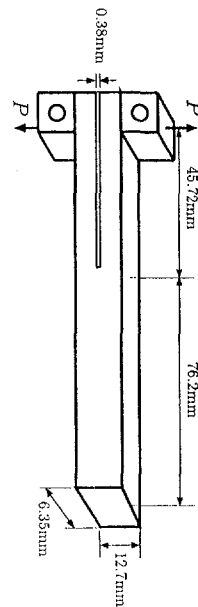
Fracture Experiment Setup For the PBX 9501

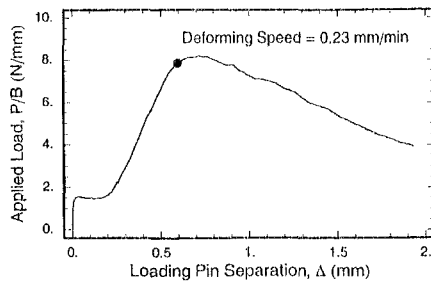


PBX 9501 Fracture Experiment

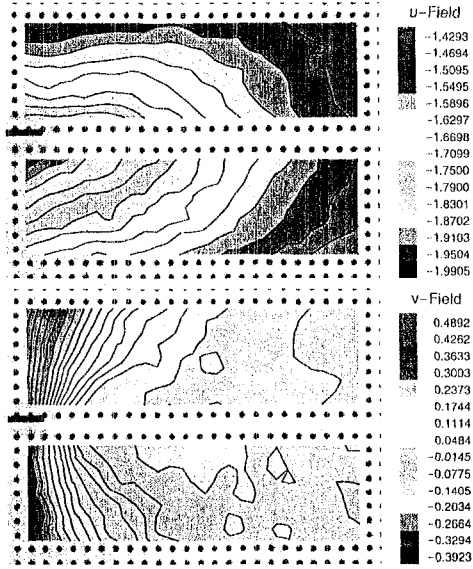


Uniaxial Fiber-Reinforced Composite (Comparison)

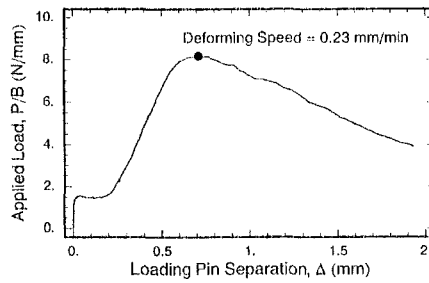
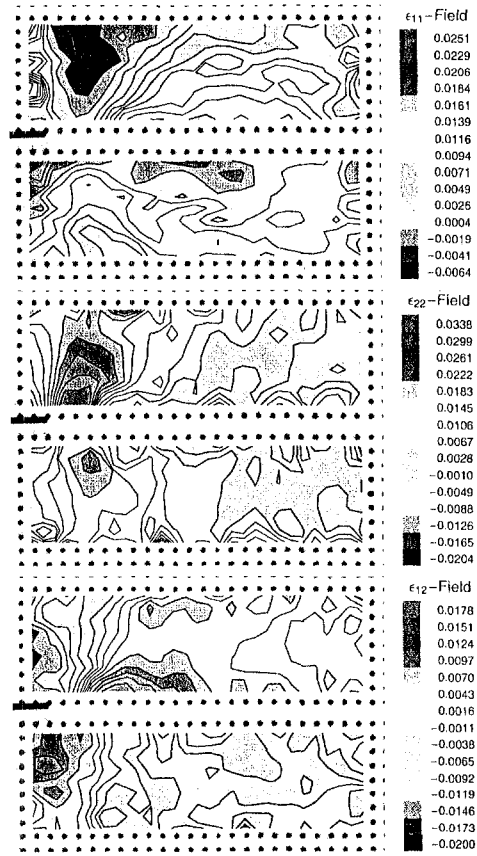




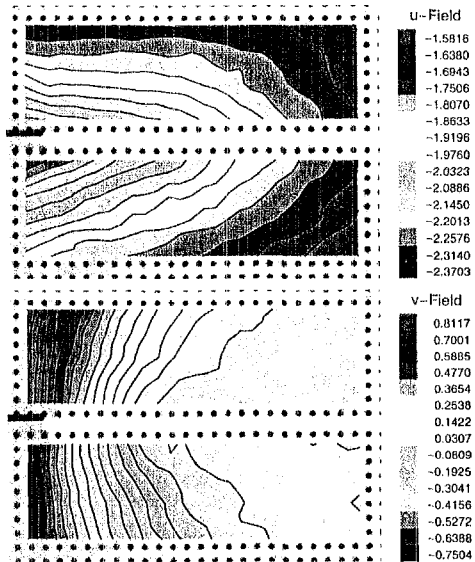
Displacement Field



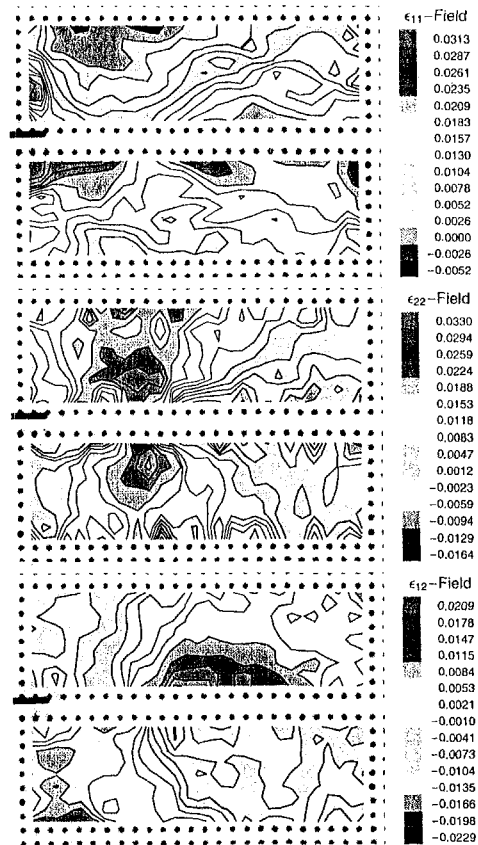
Strain Field



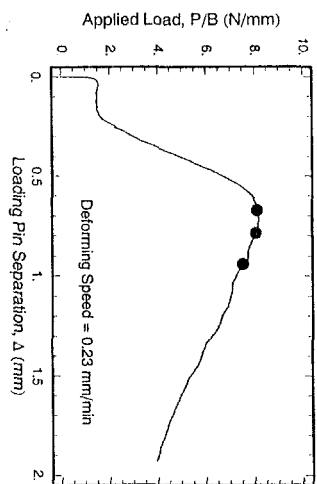
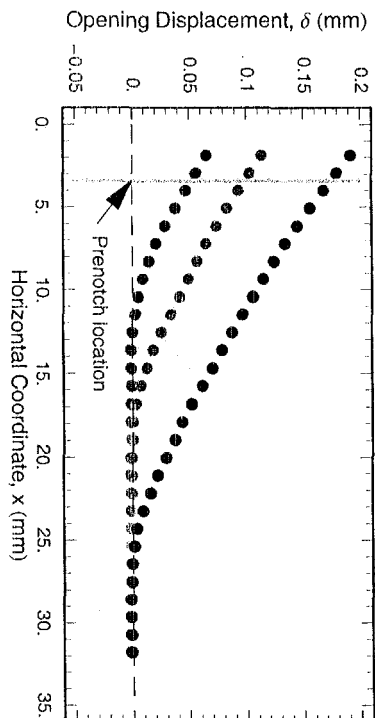
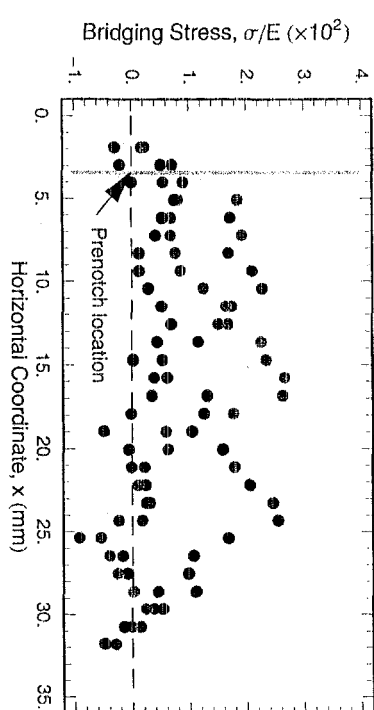
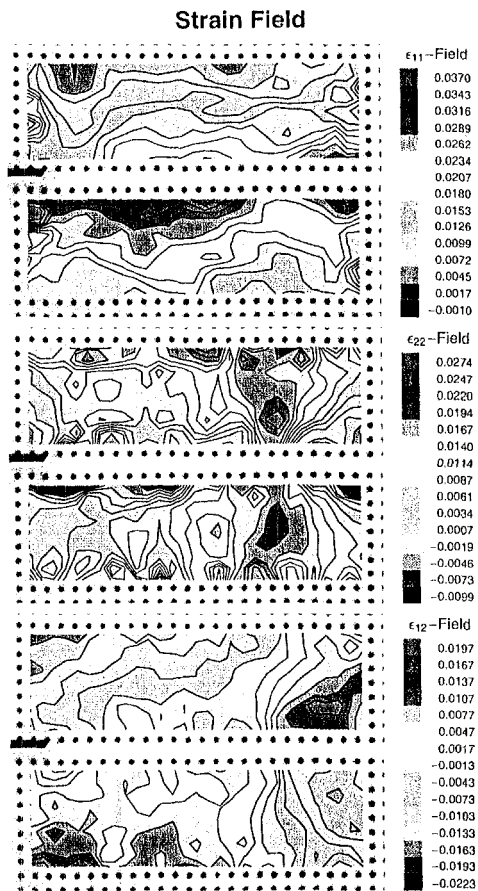
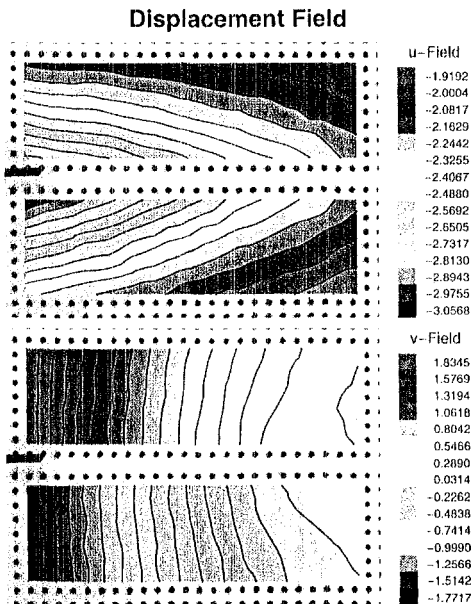
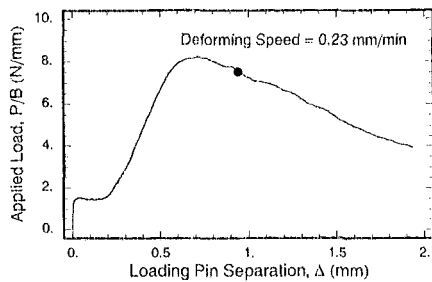
Displacement Field



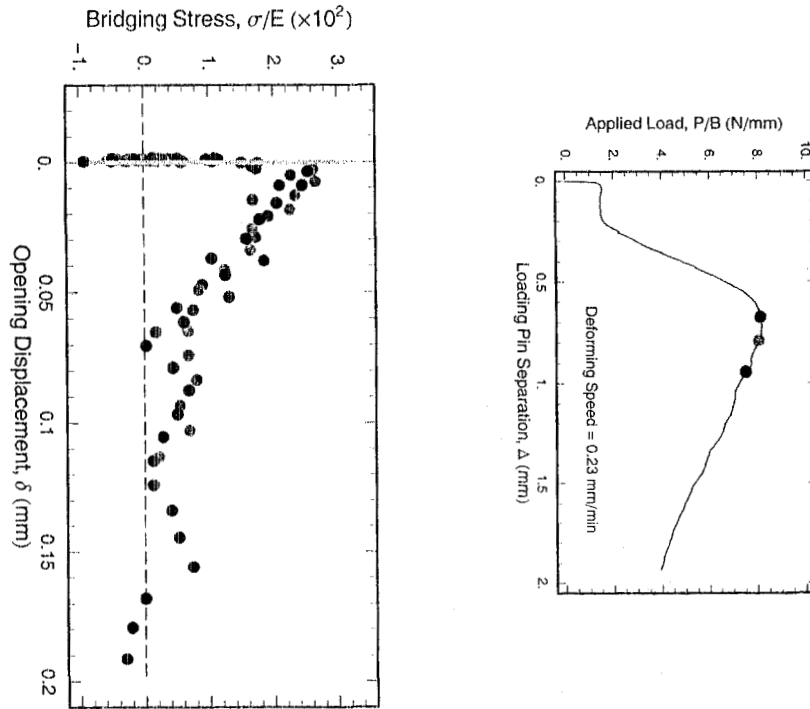
Strain Field



Opening Displacement & Bridging Stress



Stress-Bridging Law of PBX 9501



Fracture Behavior of PBX 9501: Future Plans (Wish List)

- Expanding the test matrix:
 - Loading-rate effect on stress-bridging law;
 - Effects of different environmental conditions: temperature, humidity, etc;
 - Stress-bridging law under impact loading conditions: gas gun & high speed photography;
 - Mixed-mode loading conditions: shearing.
- Improving the software package for the DIC technique.
- Numerical simulation and verification of the experimental findings:
 - ESA-EA: Joebie Gerken, Fred Smith, Joel Bennett;
 - Other analytical representations of the PBX 9501 fracture test are also welcome.
- Understand the large-scale bridging phenomenon in PBX 9501 at the microscopic level.